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Yield, Residual Nitrogen and Economic Benefit of Precision Seeding and Laser Land Leveling for Winter Wheat

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Abstract. *Rapid socio-economic changes in China, such as land conversion and urbanization etc., are creating new scopes for application of precision agriculture (PA). It remains unclear the application effective and economic benefits of precision agriculture technologies in China. In this study, our specific goal was to analyze the impact of precision seeding and laser land leveling on winter wheat yield, grain quality, residual soil nitrogen, benefit/cost ratio and net return. Three treatments was carried out in a winter wheat of the central plains of China, namely, precision seeding, integration of precision seeding and laser land leveling, and local large-scale conventional farming, respectively. Our results showed that: (1) winter wheat yield was increased by 7.8 % in the single precision seeding treatment while significantly*

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increased by 23.2 % through the integration of precision seeding and laser leveling technologies. There was no significant difference of the winter wheat protein content among the three treatments. (2) Both the single technology and the integrated technologies reduced the concentration of soil nitrate nitrogen and ammonium nitrogen at the depths of 60 cm, but, the significantly reduction was only found in soil ammonium nitrogen. (3) Compared with conventional farming, applying precision seeding improved the benefit/cost ratio by 5.9 %, and the integrated technologies improved by 16.6 % and 7.9 % under the two scenarios of "having" and "not having" laser leveling subsidies. These results clearly indicated that the application of precision agriculture technologies can significantly enhance the yield, reduce the residual soil nitrogen and improve the economic benefits, without affecting the winter wheat quality. Supporting policies can significantly promote the popularization and application of precision agriculture technologies in China.

Keywords. *Precision Seeding, Laser Land Leveling，Application Effect, Economic Benefit*

1. Introduction

It has become increasingly challenging to produce more food with limited land, water and environmental resources to meet the needs of a rapidly growing population. The purpose of precision agriculture is to improve the economic and environmental benefits of agriculture and to reduce harm to the environment, under the premise of crop yield, quality and food safety (Cassman, 1999; Gebbers and Adamchuk, 2010; Schieffer and Dillon, 2015). Current international technologies of precision agriculture mainly involve the combined application of information technologies such as Remote Sensing (RS), Geographical information System (GIS), Global Positioning System (GPS) and sensors with agricultural machineries like laser land leveling machines, planters, variable rate fertilizer applicators, spraying machines, water-saving irrigation facilities and harvesters. There are few studies about the evaluation of precision agriculture in the field. In China, the application effect and economic benefits of precision agriculture have not yet been identified, which is an important factor constraining its promotion.

Seeding as the most important part of crop production process directly impacts germination, crop growth and yield, therefore affecting the crop productivity and economic benefits (Ansari et al., 2006; Li et al., 2010). Precision seeding is the key to promoting precision agriculture, as well as the prerequisite and basis for promoting precision irrigation, precision fertilization and precision harvesting (Li et al., 2005). Precision seeding technology can not only improve the germination rate, save seeds (Arzu et al.,2007;Karayel, 2009), optimize population density, and increase crop yields (Giannini et al., 1967; Raoufat and Matbooei, 2007; Karayel, 2009), but also reduce labor inputs such as thinning and increase economic benefits (Zhao et al., 2010). The quality of land preparation is one of the important factors affecting seeding success (Ahmed et al., 2014). Laser land leveling machines can ensure precise farmland leveling, thus affecting the application of the precision seeding technology. Laser land leveling technology can effectively improve the micro-topographical conditions of farmland, thus laying the foundation for precision seeding (Xu et al., 2007). In general, it can increase crop yields (Rickman et al., 1998; Jat et al., 2006), improve the efficiency of fertilizer and water use (Jat et al., 2006; Choudhary et al., 2000; Rajput et al. 2004; Ahmed et al., 2014), and thereby increase economic benefits (Jat et al., 2009).

Most of the researches mainly focus on the application effects and economic benefits of applying one single technology. There is little research focus on integrated technologies. No attempt has been made to study the effects on the integrated technologies of precision seeding and laser land leveling in China. Therefore, this study aims to evaluate the impact of precision seeding and integrated technologies of precision seeding and laser land leveling on the winter wheat yield, residual soil nitrogen and economic benefits. The study selects winter wheat as the research object, a typical crop of the central plains of China. We conduct our experiments in Henan Province whose total wheat production and per unit yield both are the highest in China.

2. Materials and methods

2.1. Site descriptions

The experiment was conducted at 2011 National Collaborative Innovation Pilot for Modern Agriculture (113°58'26″E, 34°12'06"N), located in Changge City, Henan Province, China, typical for winter wheat-summer maize rotation. The north temperate continental monsoon climate dominates this region, with a mean annual temperature of 14.3 ℃, a mean annual precipitation of 711.1 mm, and a frost-free period of 217 d. The soil is medium textured. Topsoil (0-20 cm) organic matter is 18.40 g kg^{-1}, alkali-hydrolyzable nitrogen is101.22 mg kg^{-1}, rapidly available phosphorus is 9.83 mg kg^{-1}, rapidly available kalium is 98.44 mg kg^{-1}, and soil pH value is 7.65.

2.2. Experiment design

The experiment comprised three land levelling and seeding treatments: precision seeding (PS), integrated of precision seeding and laser land leveling (PSLL), and local large-scale conventional farming (C). The size of main plots was 300 m×150 m and of sub-plots was 50 m×50 m. There were 18 sampling points in each treatment. Precision seeding equips conventional planters with wheat seeding monitoring systems and GPS navigation systems developed by the National Engineering Research Center for Agricultural Information Technology (NERCITA) for accurate seeding, so as to precisely control the winter wheat seeding evenness, and row straightness. The 1PJ-2500 laser land leveling machinery developed by NERCITA was used for non-longitudinal cross slope leveling, with a width of 2.5 m and a leveling accuracy of 2 cm. Other treatments use conventional machineries for land leveling.

The winter wheat variety for testing was Xi Nong 979. It was planted on October 5th, 2014. The seeding amount of PS and PSLL were 195 kg ha^{-1}, and C was 225 kg ha^{-1}. The row spacing stands at 16.5 cm. 750 kg ha^{-1} compound fertilizer (N: P: K = 23:16: 6) was applied as base fertilizer for the winter wheat, and another 225 kg ha^{-1} compound fertilizer was applied in early March following the rainfall in the jointing stage. The winter wheat was irrigated once only during its growth period by local farmers with the use of conventional hose sprinklers (commonly known as the "little white dragon") (Sui et al., 2005). The amount and times of irrigation, fertilization, topdressing, spraying and other management measures of the winter wheat during its growing period were the same for all three treatments.

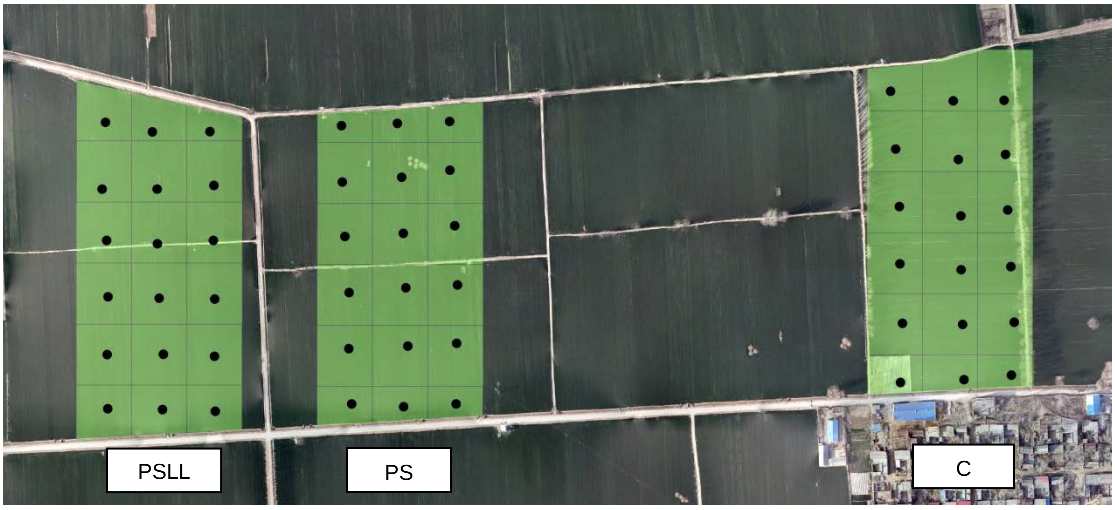

Fig. 1. Experiment design and sampling point distribution.

2.3. Sample collection and measurement method

Every treatment were setting up 18 sampling points with a spacing of 50m×50m by handheld GPS (Trimble Juno 3B). At maturity, wheat were harvested manually at1m^2 around the sampling points.The grains were threshed using a plot thresher, dried in a batch grain dryer and weighed. Grain yields of wheat was reported at 12% moisture content. Some of the grain was then crushed, mixed, sifted and measured for the Kjeldahl nitrogen content by using the Kjeldahl method(Helrich,1990), and further converted to crude grain protein content by conversion factor of 6.25. In the meantime, soil samples were taken from three spots randomly chosen around the sampling points, using an auger with a diameter of 5 cm to collect soil samples at 0-60 cm soil depth (20 cm per layer), placed in a ziplock bag and brought back to the lab. Soil moisture was measured in an oven at 105℃.Nitrate and ammonium nitrogen were extracted from fresh soil by using 1mol L^{-1} KCL solution. Soil nitrate and ammonium concentration were measured using a flow analyzer (Seal AA3).

2.4. Economics analysis

The economic analysis was done considering all inputs, including the socialized service charge for cultivation, the cost of seed, fertilizer, pesticide (irrigation water in the experimental area was free of charge) and farm management cost in this study. Land preparation, planting, fertilizer and pesticide application, irrigation, and harvesting were all done by using paid services of agricultural machinery cooperatives and farmers' cooperatives, labor inputs already included in the paid services. The farm belongs to Henan Food & Oil Group, so management cost refers to wages paid to the management personnel of the Group who were responsible for land management. The total cost was computed using the following equation:

$$\text{TCC} = C_1 + C_2 + C_3, C_1 = \sum_{i=0}^{n} \binom{n}{i} I = I_i * P_i \tag{1}$$

where TCC=total cost of cultivation, C_1=agricultural material cost, C_2= agro-mechanization Service cost, C_3= managerial pay; i=seed, fertilizer, pesticide, I_i=amount of the NO.i agricultural input, Pi= price of the NO.i agricultural input.

Gross returns (GR) were calculated by multiplying grain yield by minimum support price of wheat (0.4 US$ kg^{-1}) offered by the government of China. Net returns (NR) were calculated as the difference between gross returns and the total cost of cultivation (NR = GR-TCC). The benefit/cost ratio computed by dividing the GR by the total cost of cultivation (TCC).

2.5. Data analysis

Data were subjected to analysis of variance (ANOVA) and analyzed using the general linear model procedure of the Statistical Product and Service Solutions （SPSS16.0）. Treatment mean values were separated by Fischer’s protected least significant difference (LSD) test at $P \leqslant 0.05$.

3. Results

3.1. Grain yield and crude protein

Of all the 18 sampling points in each of the three treatments, 33% of PS had a grain yield higher than 8,000 kg ha^{-1}, 83% of PSLL had a grain yield higher than 8,000 kg ha^{-1}, and only 22% of C had a grain yield higher than 8,000kg ha^{-1} (Figure 2). In terms of average yield, PS and PSLL significantly increase grain yield of winter wheat. PS increased winter wheat grain yield by 7.8%, while PSLL increased by 23.2%.Average crude protein content of PS, PSLL and C were 13.6%, 13.6% and 13.7% respectively, the difference was no significance.

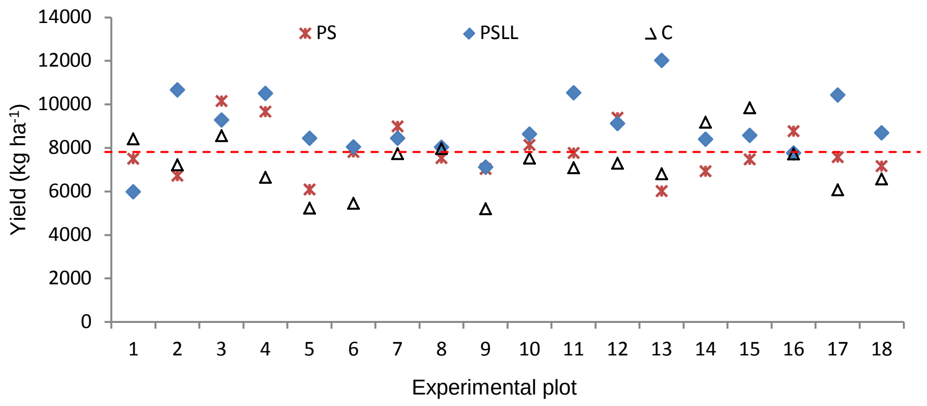

Fig. 2. Wheat yield at the 18 sampling points in each of the three treatments.

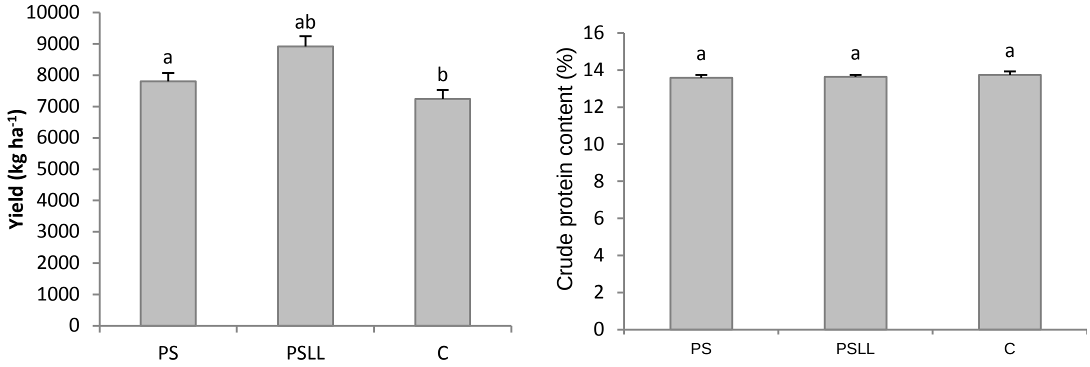

Fig. 3. Grain yield and crude protein content (lowercase letters indicate significant differences).

3.2. Residual nitrogen

After the winter wheat harvest, soil residual nitrate nitrogen concentration decreased as soil depth increases, under three treatments. Compared with conventional farming, precision agricultural practices tend to reduce soil residual nitrate content, however, the difference was no significance. PS reduced more nitrate nitrogen than PSLL. Compare with that of C, soil residual nitrate nitrogen concentration at depth of 0-60 cm in PS and PSLL reduced 7.9% and 4.9%, respectively.

Soil residual ammonium nitrogen concentration of different layers of soil in the three treatments was similar. It was slightly higher in soil at 20-40cm depth than other layers. Precision agricultural practices significantly reduced the soil ammonium nitrogen concentration ($P \leqslant 0.05$). PSLL was more effective than PS in reduce the soil ammonium nitrogen concentration. Soil ammonium nitrogen concentration at depth of 0-60 cm in PS and PSLL was reduced by 26.3% and 38.2%, respectively, and there were no significant differences under the two treatments.

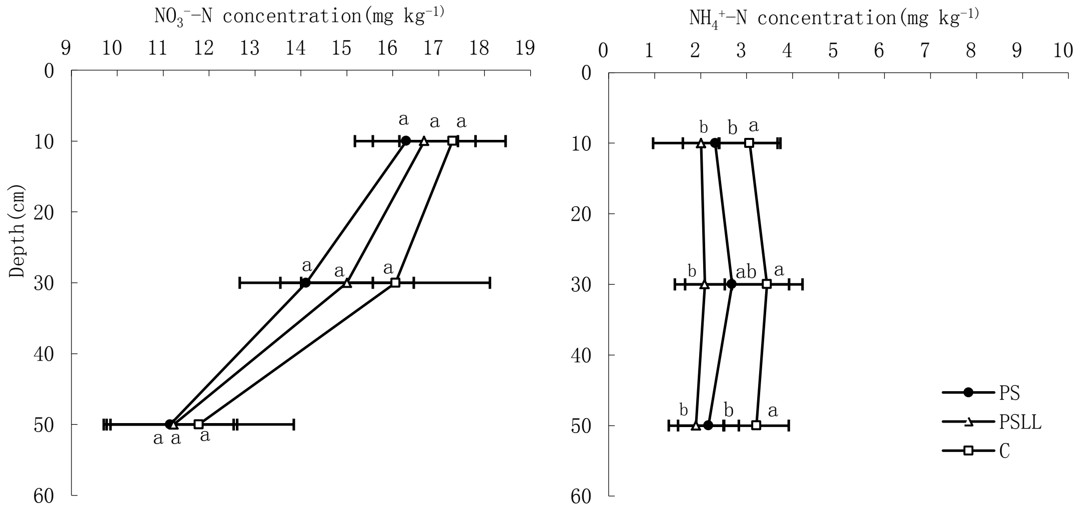

Fig. 4. Soil nitrate and ammonium nitrogen concentration at depth of 0-60cm during wheat harvest (lower case letters indicate significant differences P <0.05).

3.3. Spatial variability

Spatial variability of soil residual nitrate nitrogen and ammonium nitrogen (inorganic nitrogen) concentration of 0-20 cm layer was high, that of yield was medium, and that of grain protein content was very low. Spatial variability of winter wheat yield is lower under PS and PSLL, compared with that under C, with the spatial variability of yield being the lowest under PS. PS and PSLL didn't reduce the spatial variability of grain protein content and inorganic nitrogen concentration in the surface soil (0-20cm).

Table 1. Spatial variability of grain yield, protein content and soil inorganic nitrogen concentration at depth of 0-20cm under different treatments.

Variables	Treatments	Number of sampling points	Max.	Min.	Mean	S.D.	C.V. %
Yield (kg ha^{-1})	PS	18	10149.8	5997.3	7805.5	1173.7	15
	PSLL	18	12015.3	5969.8	8919.6	1456.2	16.3
	C	18	9836.2	5196.8	7242.8	1293.8	17.9
Crude protein content (%)	PS	18	14.6	12.8	13.6	0.6	4.8
	PSLL	18	14.8	12.6	13.6	0.7	5
	C	18	14.9	12	13.8	0.8	5.7
Soil Inorganic nitrogen concentration of 0-20cm layer (%)	PS	18	33.9	10.4	18.5	5.8	31.1
	PSLL	18	29.9	12	18.7	5.9	31.8
	C	18	36.4	11.8	20.4	6.4	31.3

3.4. Economic benefit

Inputs of the 2014-2015 winter wheat are shown in Table 2. Inputs of C were

1,359.1 US$ ha^{-1}. Inputs of PS and PSLL were higher than that of C. Conventional inputs were 1,342.4 US$ ha^{-1}. Compared with C, PS and PSLL had additional costs of laser land leveling, seeding monitoring and GPS navigation. These costs were, in this study, calculated as service charges, among which the laser land leveling charge was 185.3 US$ ha^{-1}, and seeding monitoring and GPS navigation charge was US$23.2 per hectare. The Chinese government currently subsidies laser land leveling. Taking Tianjin for example, the rate of the government subsidy is US$115.8 per hectare (Tianjin Agricultural Bureau, 2015). Therefore, the fees of precision agriculture for PS and PSLL were 92.6 US$ ha^{-1} with laser land leveling subsidies and 208.4 US$ ha^{-1} without laser land leveling subsidies. As shown in Table 2, compared with C, benefit/cost ratio of PS increased by 5.9%, while that of PSLL increased by 16.6% with laser land leveling subsidies or 7.9% without the subsidies. Net return of winter wheat under PS increased by 185.4 US$ ha^{-1}, while that under PSLL increased by 545.4 US$ ha^{-1} (with laser land leveling subsidies) or 429.6 US$ ha^{-1} (without subsidies).

Table 2. Management measures of wheat fields during 2014-2015 in different treatments.

Management	Input	Unit	PS	PSLL	C
Basal dressing (compound fertilizer, N:P:K=23:16:6)	Amount of fertilizer	Kg ha^{-1}	750	750	750
Land preparation	Service fees for mechanical plowing and returning straw	US$ ha^{-1}	185.3	185.3	185.3
	Laser land leveling fees (with/without subsidies)	US$ ha^{-1}	0.0	69.5/185.3	0.0
Seeding	Seeds	Kg ha^{-1}	195	195	225
	Seeder fees	US$ ha^{-1}	23.2	23.2	23.2
	Seeding monitoring and GPS navigation fees	US$ ha^{-1}	23.2	23.2	0.0
Topdressing (compound fertilizer N:P:K=23:16:6)	Amount of fertilizers	Kg ha^{-1}	225	225	225
	Fertilizer distributor fees	US$ ha^{-1}	4.6	4.6	4.6
Irrigation(once during 2014-2015)	Electricity + labor costs	US$ ha^{-1} $Time^{-1}$	92.6	92.6	92.6
	Pipe costs	US$ ha^{-1} $Season^{-1}$	308.8	308.8	308.8
Spraying	Herbicide (chemicals+ machinery fees)	US$ ha^{-1}	16.2	16.2	16.2
	Pesticide (chemicals+ machinery fees)	US$ ha^{-1}	18.5	18.5	18.5
	Prevention of pests, dry hot wind and lodging (chemicals+ air spray)	US$ ha^{-1}	34.7	34.7	34.7
Harvesting	Harvester fees	US$ ha^{-1}	69.5	69.5	69.5
Wages of management personnel		US$ ha^{-1}	13.9	13.9	13.9

Note: rate of laser land leveling subsidies is 115.8 US$ ha^{-1}.

Table 3. Economic benefits of different wheat treatments during 2014-2015.

Economic indicators	PS	PSLL		C
		With subsidies	Without subsidies	
Conventional agriculture cost (US$ ha^{-1})	1342.4	1342.4	1359.1	1359.1
Precision agriculture cost (US$ ha^{-1})	92.6	208.4	23.2	0.0
Total cost of cultivation (US$ ha^{-1})	1435.1	1550.9	1382.3	1359.1
Gross benefit(US$ ha^{-1})	3305.2	3305.2	2892.4	2683.9
Net return(US$ ha^{-1})	1870.2	1754.4	1510.1	1324.8
Benefit/cost ratio	2.30	2.13	2.09	1.97

Note: According to the e-commerce platform Jingdong, compound fertilizer is 0.5 US$ kg^{-1} and seed is 0.6 US$ kg^{-1}.

4. Discussion

4.1 Grain yield and crude protein

Our results indicated that precision seeding and integration of precision seeding and laser land leveling technologies could significantly increase grain yield of winter wheat by 7.8% and 23.2%, respectively. The results was agreements with the previous studies that application of precision seeding and laser land leveling technologies could improve crop yield by 5% -20% (Li et al., 1999; Li et al., 2005;Jat et al., 2006,2009). PSLL was more effective than PS in increasing the yield. This was attributed to the following aspects. First, laser land leveling improves farmland flatness (Aquino et al., 2015), makes planting depth even, improves crop germination and its growth environment (Burce et al., 2013; Marlowe et al.,2013), increases crop population density to increase yield (Rickman J.F. et al., 1998; Jat et al., 2006), and enhances the effect of precision seeding. Second, precision seeding ensures evenness of seeding (Yazgi and Degirmencioglu, 2007), reduces seeding absence and reseeding, improves germination, optimizes the crop population density, and gives full play to the advantage of laser land leveling in improving water and fertilizer utilization efficiency (Jat et al., 2006; Sharifi et al., 2014). In a word, laser land leveling and precision seeding complement each other so as to significantly improve crop yield.

Crop grain quality depends not only on its genotype, but also on the environment and crop cultivation practices (Souza et al., 2004; Otteson et al., 2008). Such cultivation practices as seeding time (Gao et al., 2012), seeding density (Zhang et al., 2016), seeding methods (Reddy et al., 2003) and others are closely related to wheat grain protein content. Laser land leveling can have an impact on soil water and salt distribution (Ahmed et al., 2014), soil aggregates, particle size, infiltration resistance of soil and other soil physical properties (Jat et al., 2006; Walker et al., 2003). Soil fertility (Shaw, 1998), soil moisture (Guttieri et al., 2000), soil type, nature, structure (Ayoubi et al., 2014; Diacono et al., 2012), etc. also have impact on wheat protein and other qualities. Another studies shows that there are not significantly influenced by the tillage system (Bilalis et al., 2011; Cociu and Alionte, 2011).The results of this study show that PS and PSLL had no significant impact on the protein content of wheat. Because lack of the nitrogen balance and soil structure data of this three treatments, the reason need to be explained by further research.

4.2 Residual nitrogen

Soil nitrate and ammonium nitrogen residues after harvest increase the risk of nitrogen leaching losses (Fang et al., 2006). Researches found that precision agriculture technologies by increasing nitrogen utilization efficiency can reduce soil nitrogen residues (Chen, 2003; Diacono et al., 2013), but there are also studies suggesting that precision agriculture technologies cannot reduce soil nitrate nitrogen residues (Ferguson et al., 2002; Link et al., 2006). In this study, PS and PSLL tend to reduce the level of soil nitrate and ammonium nitrogen residues after the winter wheat harvest (Fig. 4). In particular, the two treatments significantly affected the ammonium nitrogen concentration. The main reason is that the two treatments significantly increase winter wheat's utilization of the surplus nitrogen, thereby reducing the nitrogen residues (Hatfield, 2000; Thrikawala et al., 1999). PSLL was less effective than PS in reducing nitrate nitrogen, mainly because the laser land leveling process crushes the farmland for multiple times, increasing the soil density, slowing down the moisture downward infiltration (Ahmed et al., 2014), and resulting in retention of the nitrate nitrogen that moves easily with water in the surface soil. However, PSLL was more effective than PS in reducing the ammonium nitrogen concentration, mainly because winter wheat grows better under PSLL, more nitrogen is absorbed and unlike nitrate nitrogen, ammonium nitrogen does not move easily with water.

4.3 Spatial variability

Precision agriculture technologies control the input of seeds, fertilizers, chemicals and other agricultural inputs mainly based on the spatial characteristics of soil (Kamgar et al., 2015). Years of precision management can reduce soil spatial variability (Wang et al., 2009). This study finds that compared with conventional farming, Model A and Model B could reduce the spatial variability of winter wheat yield, and spatial variability is the lowest under Model A. The reason should be that Model A reduces germination differences in each area within the treatment (Arzu et al.,2007; Karayel, 2009), thereby reducing spatial variability of the post-harvest yield. But didn’t reduce the spatial variability of the concentration of inorganic nitrogen, due to soil movement while lower parts of a field being filled and higher parts being cut, previous sub-surface soil layers may be exposed to the surface(Aquino et al., 2015).

4.4 Economic benefit

As for whether the application of precision agriculture technologies can increase economic benefits, there are two opinions, that is, positive gains (Jat et al., 2009;

Tozer, 2009) and no changes (Chen, 2003). Experiment results in the rice-wheat rotation field show that application of the laser land leveling technology increases farmers' annual income by $145 ha^{-1} (Jat et al., 2009; Peter, 2009). Application of multiple precision agriculture technologies can achieve higher earnings than single technology application (Finck, 1998;Lowenberg-De-Boer, 2000). This study calculates the benefit/cost ratio and net return of different treatments to identify the economic benefits of applying precision agriculture technologies. Results show that both PS and PSLL could increase the economic benefits of winter wheat production, with PSLL being more effective. The author have interviewed farmers in the experimental region about precision agriculture, and found that unclear economic returns were one of the main obstacles hindering them from applying the technology. Making clear the economic benefits of using precision agriculture technologies will greatly contribute to the popularization and application of the technologies in the region. Meanwhile, developing policies that encourage social services such as subsidies for precision agriculture technologies can help further promote the popularization and application of precision agriculture technologies in China.

Results of this study were based on one year's application of precision agriculture technologies, conclusions of which need further validation.

5. Conclusions

(1) Compared with the local conventional large-scale farming, both Precision seeding and integration of precision seeding and laser leveling significantly increased the yield of winter wheat, with integration of precision seeding and laser leveling being more effective. They could reduce spatial variability of yield at the same time. However, they had no significant impact on the grain protein content of the in-season wheat crops.

(2) Precision seeding and integration of precision seeding and laser leveling reduced the soil nitrate and ammonium nitrogen concentration at 0-60cm layer after the wheat harvest compared with conventional farming, particularly the concentration of ammonium nitrogen.

(3) In terms of economic benefits, precision seeding increased the benefit/cost by 5.9%, while integration of precision seeding and laser leveling increased the benefit/cost ratio by 16.6% with laser land leveling subsidies in place or 7.9% without the subsidies.

Future studies, more researches should be carried out to evaluate the applincation effective and efficiency of different integration models of precision agriculture technologies including variable fertilization, variable spraying, variable irrigation and other measures, in order to find a better precision agriculture system with higher economic and environmental benefits for the dryland farming in the central plains of China.

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